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DESIGN, FABRICATION AND EVALUATION OF LOW COST DIODE OSCILLATOR--ETC(U)
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DESIGN, FABRICATION AND EVALUATION OF LOW COST DIODE OSCILLATOR FOR MILLIMETER WAVES

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April 1980

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There are urgent requirements for millimeter-wave oscillators in the range of 60 GHz, particularly for local oscillators, receivers, and low power transmit/receive applications such as the self-oscillating mixer. This report describes the design, fabrication and evaluation of a low cost Gunn diode oscillator structure where the diode is placed adjacent to a dielectric waveguide, which in turn, provides output coupling for radiation. Ten milliwatt output power was obtained from a diode at a frequency of 60 GHz.

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DESIGN, FABRICATION AND EVALUATION OF

LOW COST DIODE OSCILLATOR FOR MILLIMETER-WAVES

INTRODUCTION

This project was undertaken to demonstrate the feasibility of fabricating a low cost diode oscillator.[1] Indium Phosphide and gallium arsenide diodes were designed into a package where sufficient power was obtained for applications to the development of low power transmitter/receivers. Present day oscillators consist of a diode (Gunn or IMPATT) mounted in a metal cavity, costing about $3,000 for a single unit because of precision machining required for the cavity walls. The aim of this project was to design a low cost, simplified circuit package where maximum power could be obtained from the Gunn diode at a desired frequency with nearly fixed impedance so that little or no tuning is required.

CIRCUIT DESIGN AND PACKAGING

Preliminary design and packaging was directed toward establishing the relative locations of components to minimize power loss, due to radiation, in the passive dielectric transmission line and the oscillating diode region. A detailed illustration (Fig. 1) shows the basic solid state oscillator diode's structural design and package in pellet form. It is a gallium arsenide or indium phosphide solid state diode approximately 0.0102cm x 0.0102cm x 0.0051cm (0.004 in. x 0.004 in. x 0.002 in.) and is eutectically bonded to a gold-plated copper disc cover approximately 0.0889cm (0.035 in.) in diameter. The device is surrounded by a quartz ring 0.0127cm (0.005 in.) high with a 0.0127cm (0.005 in.) thick wall. The anode or top of the diode is interconnected with gold ribbon 0.0051cm x 0.0025cm (0.002 in. x 0.001 in.) to the top surface of the quartz ring. The assembly is capped with the gold-plated copper disc. The Gunn diode oscillator, in pellet form, as shown in Figure 2, is then soldered in a small vertical hole drilled in a gold-plated copper block 1.3462cm x 0.7620cm x 0.2540cm (0.530 in. x 0.300 in. x 0.100 in.) for base bonding and also serves as a heat sink. The pellet diode is soldered in the cavity with 60-37-3 silver solder at 220^{o}C. The next assembly step consists of bonding a dielectric waveguide adjacent to the diode and then bonding the diode with dielectric waveguide and heat sink on a 2.5400cm x 0.0508cm (1.000 in. x 0.020 in.) gold-plated alumina carrier substrate (Fig. 3). The dielectric waveguide tapered at one end is machined from alumina, is 2.540cm (1.000 in.) long, 0.3048cm (0.120 in.) wide, and 0.1016cm (0.040 in.) thick. By utilizing impedance transformer concepts and subsequent experimentation, it was found that by placing metal strips along the dielectric waveguide's upper surface, power output can be increased significantly. On the top part of the dielectric waveguide two metal strips 0.2032cm (0.080 in.) wide were placed alongside each other spaced 0.0127cm (0.005 in.) apart; in addition, a metal strip 0.0254cm (0.010 in.) wide was placed beside the dielectric, adjacent to the diode. The metal strips serve as transformers to match the diode and resonant disc to the dielectric transmission lines. The diode structure was then inclosed in a rectangular metal guide. For simplicity and ease in structure, the

[1] This report is being written in support of Patent Disclosure No. 1969.

dielectric waveguide was bonded to the heat sink with conductive silver epoxy "Ablestick 71-1", cured for 10 minutes at 165°C, then for 10 minutes at 200°C. The heat sink block, with dielectric bonded on it, was bonded to the metallized alumina carrier substrate with 60-40 tin lead solder at 188°C utilizing flow solder technique. The diodes investigated were designed to oscillate at 50-60 GHz and it was appropriate to inclose the diode assembly within a standard V-band waveguide. Diode assembly inclosure and waveguide size are shown in Figure 4. A clearance hole is drilled through the V-band waveguide directly above the diode assembly for insertion of a microwave connector for contact with the anode surface of the diode (Fig. 5). The RF connector was modified by adding two discs to the positive bias; the lower disc serves as a resonant tuner, the upper disc as a choke. The first disc, nearest to the surface of the dielectric is 0.2286cm (0.090 in.) in diameter and is positioned so that when contact is made with the diode the disc will be approximately 0.0254cm (0.010 in.) above the surface of the dielectric. The second disc, slightly larger, is 0.2794cm (0.110 in.) in diameter, is positioned so that it will be approximately 0.0762cm (0.030 in.) above the first disc and is also approximately the same distance from the base of the RF connector. The entire assembly (Fig. 6) is placed in a metal box (cover) 4.2cm x 3.8cm; mounted in the V-Band waveguide to the rear, is a slide screw tuner. The front of the waveguide section is open with the dielectric pointed section protruding. The bias to the diode is fed from the top through a coaxial line.

DATA

Test results and parameters recorded were obtained from tests set up in the standard V-Band waveguide. Table 1 shows test results of the first GaAs Gunn diode assembled on a metal block with a 0.254cm (0.1000 in.)diameter disc attached to the anode. Table 2 gives test results of a second GaAs Gunn diode where 10 mW was obtained. Table 3 gives test results from a third GaAs Gunn diode (73-1); 7.4 mW was obtained. The diode was accidentally shorted before accurate frequency measurements could be obtained. Table 4 gives test results from a screw type GaAs Gunn diode. A photograph of the entire assembly is shown in Figure 7. In testing these oscillators, power and frequency were directly measured. The Q_{ext} or Q_{loaded} were not measured. Testing these units as self-oscillating mixers, it was determined that oscillator spectrums were sufficiently narrow to be used in this application or for transmitters and receivers.

DISCUSSION

In considering the most important factors in the design of this oscillator, it is first assumed that the diode has relatively small parasitics and a low negative resistance. Given these factors the following items are of concern:

a. The tuning disc on the top of the diode is the first and most important requirement. Theory [2] indicates that this disc is essentially an open circuited quarter-wavelength line with the diode at the input providing a low-negative resistance generator. This factor is well established and tuning discs have been used for IMPATT and Gunn diodes in metal walled cavities.

[2] S. Ramo, J. R. Whinnery and T. VanDuzer, "Fields and Waves in Communications Electronics", John Wiley & Sons, Inc. New York, 1967, pp. 453-457.

b. The second most important factor is that the flat metal stripes on top of the Al_2O_3 (or silicon) dielectric waveguide greatly enhance coupling of power from the diode disc resonator to the dielectric waveguide.[3] These metal stripes are essentially transformers from the disc edges to the dielectric transmission line. The actual length of transformer stripes used was determined empirically. It is further noted that the Gunn diode can be placed outside the dielectric or in a hole cut into the dielectric line. The stripe transformers thus provide a great deal of freedom of choice.

c. The mechanical slide screw tuner is of lesser importance, and the fact that it changed the frequency very little indicates a high Q resonant circuit for the oscillator.

d. Finally the transformer stripes must be covered with a metal wall to prevent radiation. In fact, the entire structure was covered with a second metal box. It appears that any diode imbedded in a dielectric or placed near the rear side of the dielectric will radiate into space. The dimensions of these metal covers is not critical since most of the power is in the dielectric; however, covers are necessary to prevent emanating radiation for specific applications, such as local oscillators, transmitters, etc. The metal covers may not be required for beacon applications or where the oscillator is required as a separate assembly to be placed in a waveguide at the discretion of the user for his own purposes.

The design parameters used in the fabrication of the diode oscillator are preliminary and thus considerable potential for upgrading exists in this particular structure. The metal box's (cover) dimensions could be at least one-third smaller thus minimizing energy losses due to multimode reflections from the walls of the large box. The base of the dielectric should be metallized and soldered to the diode heat sink block. The transformer stripes, when the proper dimensions are established, should be metallized permanently in the dielectric, insuring good bias and low skin effect losses and presumably increasing the radiation energy into the dielectric.

CONCLUSIONS

Based upon test results, sufficient power was obtained for local oscillator applications. Significant achievements obtained were small size, simplicity of structure, and good output. This data clearly demonstrates the potential for designing special custom oscillators employing solid state diodes.

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[3] M.M. Chrepta and H. Jacobs, "Self-oscillating Mixers in Dielectric Waveguide," Research and Development Technical Report, ECOM-4514, August, 1977.

Table 1: Test Results GaAs Gunn Diode Assembled On Metal Block With 0.2540cm (0.1000 in.) Diameter Disc Attached to Anode

DIODE	OPERATION		POWER	FREQUENCY	REMARKS
	Volts	Amps	mW	GHz	
Diode assembled in metal block with 0.2540cm (0.1000 in.) diameter disc attached to Anode 72-1	2.5	2.0	1.2		
	3.5	2.0	2.5		
	3.5	2.2	2.8		
	3.4	2.0	2.9		
	3.4	2.0	2.9		
	3.4	2.0	2.9		
	3.7	2.0	3.0		
	3.4	2.0	3.0		
	3.4	1.9	3.0	50.42	
	4.0	1.8	4.2	50.48	
	3.5	1.8	4.4		Tuned with slide screw
	3.9	1.7	4.3		
	4.0	1.78	5.0	50.40	
	3.7	1.8	4.0		
	3.6	1.8	4.2		Tuned with slide screw

Table 2: Pellet Form GaAs Gunn Diode
Assembled on Metal Block

DIODE	OPERATION		POWER	FREQUENCY	REMARKS
	Volts	Amps	mW	GHz	
73-5	0.5	0.6			
Pellet Form	0.8	1.0			
0.2286cm	1.2	1.4			
(0.090 in.)	1.8	2.0			
Cap	2.0	2.0			
	2.5	1.8			
	2.6	1.8	0.8		
	2.7	1.8	1.0		
	2.8	1.8	3.0		
	2.9	1.8	3.4		
	3.0	1.8	4.0		
	3.0	1.8	4.6	59.1	
	3.1	1.8	5.0	59.12	Tuned with slide screw
	3.2	1.8	5.2	59.02	
	3.2	1.8	5.4	58.92	
	3.2	1.8	6.0		Tuned with slide screw
	3.2	1.8	6.2	58.98	
	3.0	1.8	7.0		
	3.1	1.8	8.0	59.1	
	3.2	1.7	9.0	58.28	Tuned with slide screw
	3.2	1.7	10		
	3.3	1.8	10		

Table 3: Pellet Form GaAs Gunn Diode
Assembled On Metal Block

DIODE	OPERATION		POWER	FREQUENCY	REMARKS
	Volts	Amps	mW	GHz	
73-1	0.5	0.6			
Pellet Form	0.6	0.9			
0.2286cm	0.7	1.1			
(0.090 in.)	0.9	1.2			
Cap	1.5	1.4			
	2.0	1.6			
	2.3	1.9			
	2.5	2.0			
	2.5	1.8	4.0		
	2.7	1.8	4.4		
	2.8	1.8	4.6		
	2.8	1.8	5.0		
	2.6	1.8	5.4		Tuned with slide screw.
	2.6	1.8	5.8		
	2.6	1.8	6.0		
	2.6	1.8	6.4		Tuned with slide screw.
	2.7	1.8	7.0		
	2.8	1.8	7.2		
	2.8	1.8	7.4		

Table 4: GaAs Gunn Diode

DIODE	OPERATION		POWER	FREQUENCY	REMARKS
	Volts	Amps	mW	GHz	Placed shield over transformer strips on dielectric
Microwave Assoc.					
Screw Type Diode	3.0	1.2	4.0		
No. 0411016	3.0	1.2	6.0		Tuned with slide screw.
Vendor's Rating	3.1	1.2	10.0		Increased bias voltage.
VT = 1.26V					
IT = 1.384A					
Vop = 3.6V					
Iop = 1.061A					
	3.1	1.2	18.0		Tuned with slide screw.
	3.2	1.2	20.0		Increased bias volt.
	2.8	1.2	15.0	47.5	Inserted B band
	2.8	1.2	15.0	47.5	frequency meter.
	2.8	1.2	15.0	47.6	
	2.8	1.2	7.4	48.0	Decreased power by tuning effect with slide screw plunger.
	2.5	1.2	7.0	47.5	Maximum tuning with decreased voltage.
	2.7	1.2	8.0	47.5	Increased bias volt.
	2.9	1.2	9.0	47.5	Increased bias volt.
	3.0	1.2	10.0	48.5	Increased bias volt.

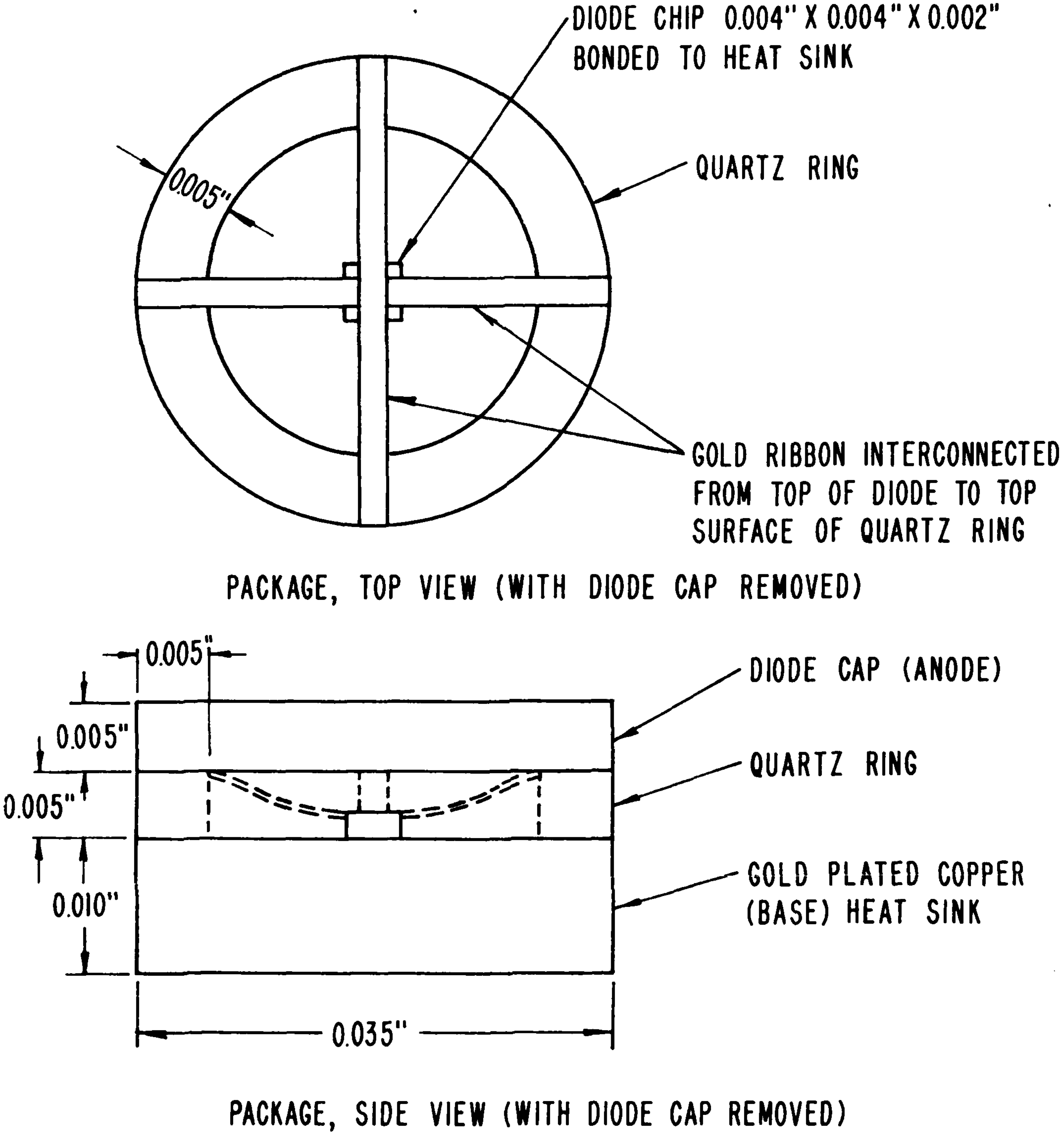


Figure 1. Gunn Diode Packaged in Pellet Form

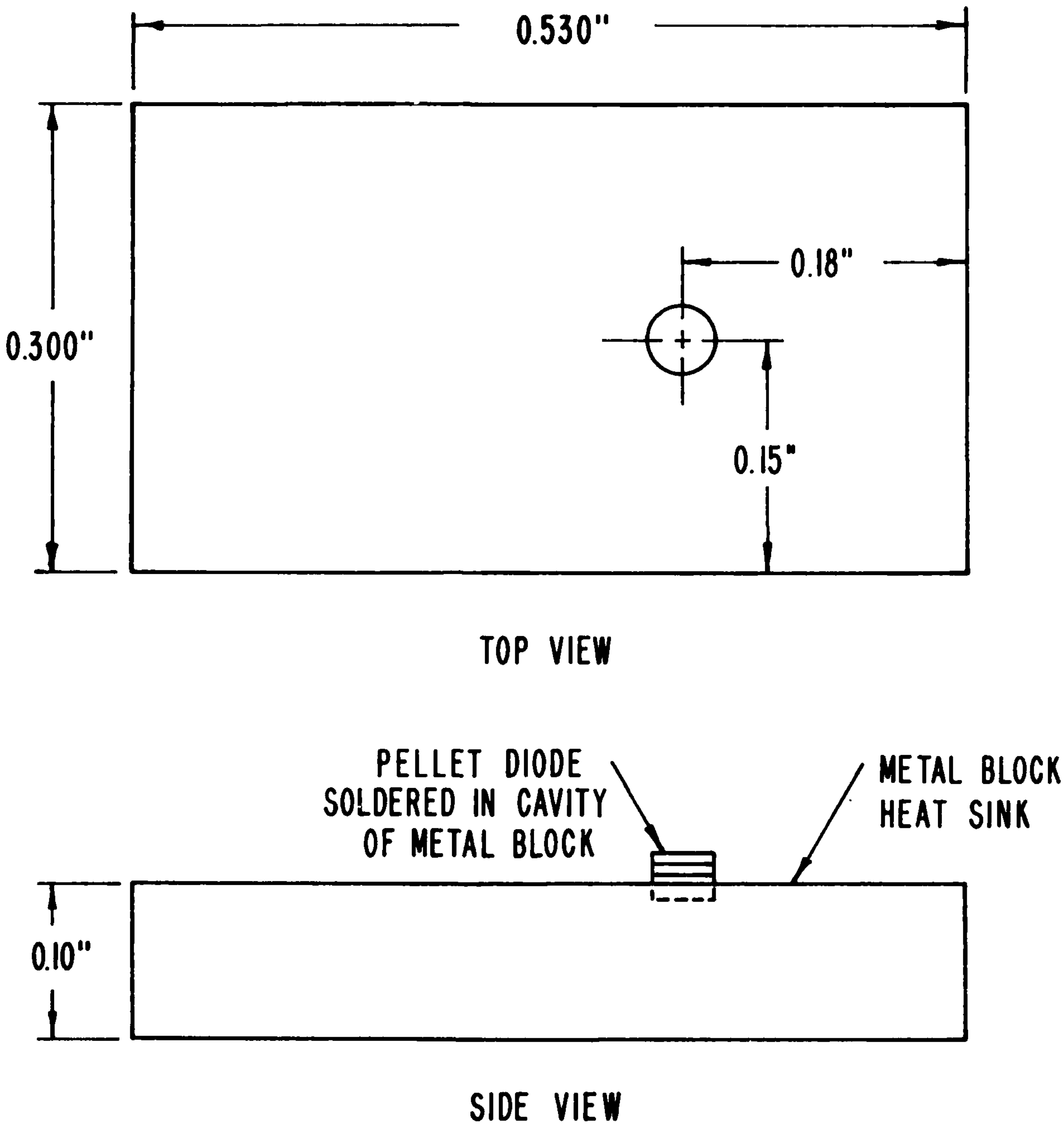


Figure 2. Pellet Diode Soldered to Metal Block for Base Bending and Heat Sink

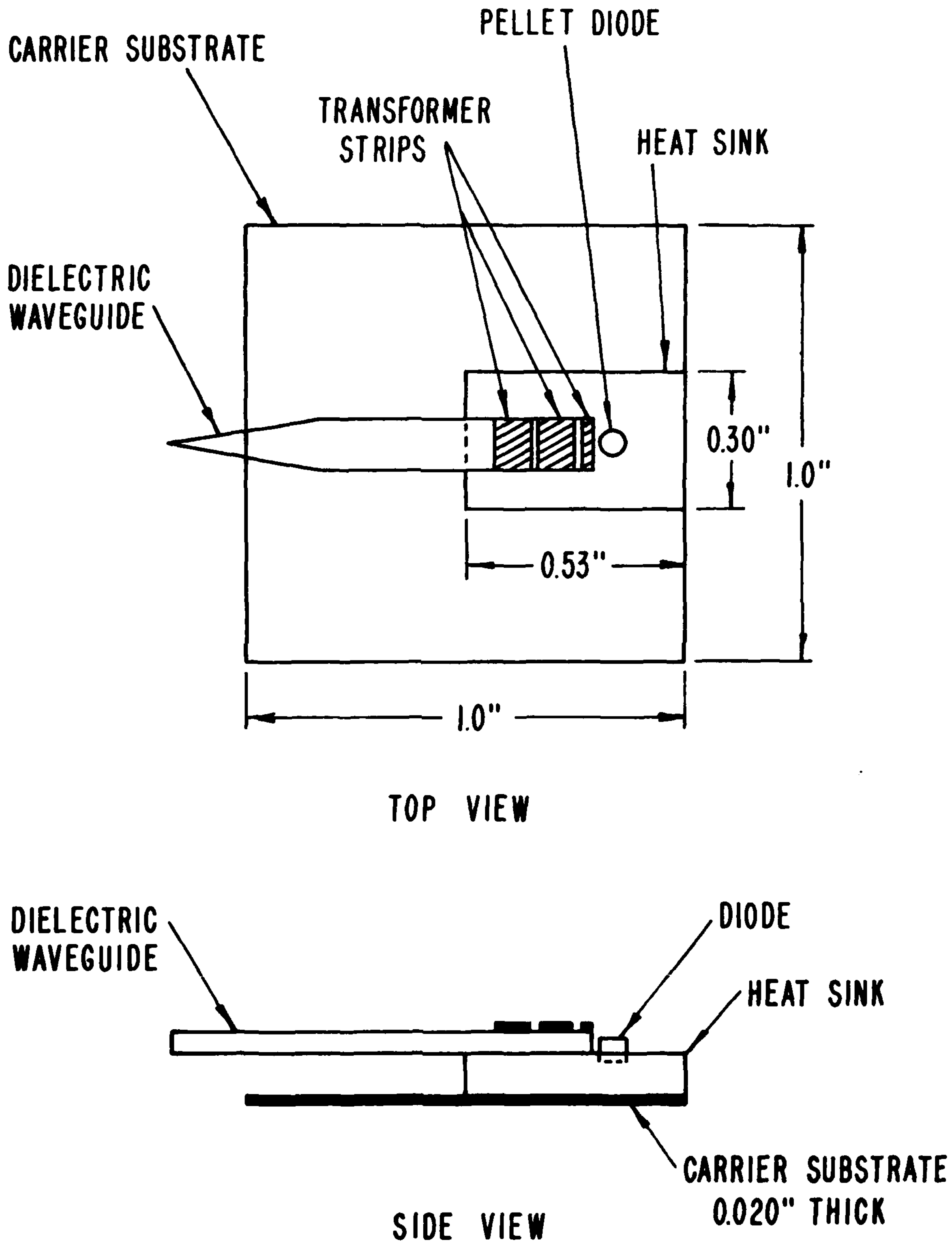


Figure 3. Dielectric Waveguide with Transformer Strips Bonded on Heat Sink and Carrier Substrate

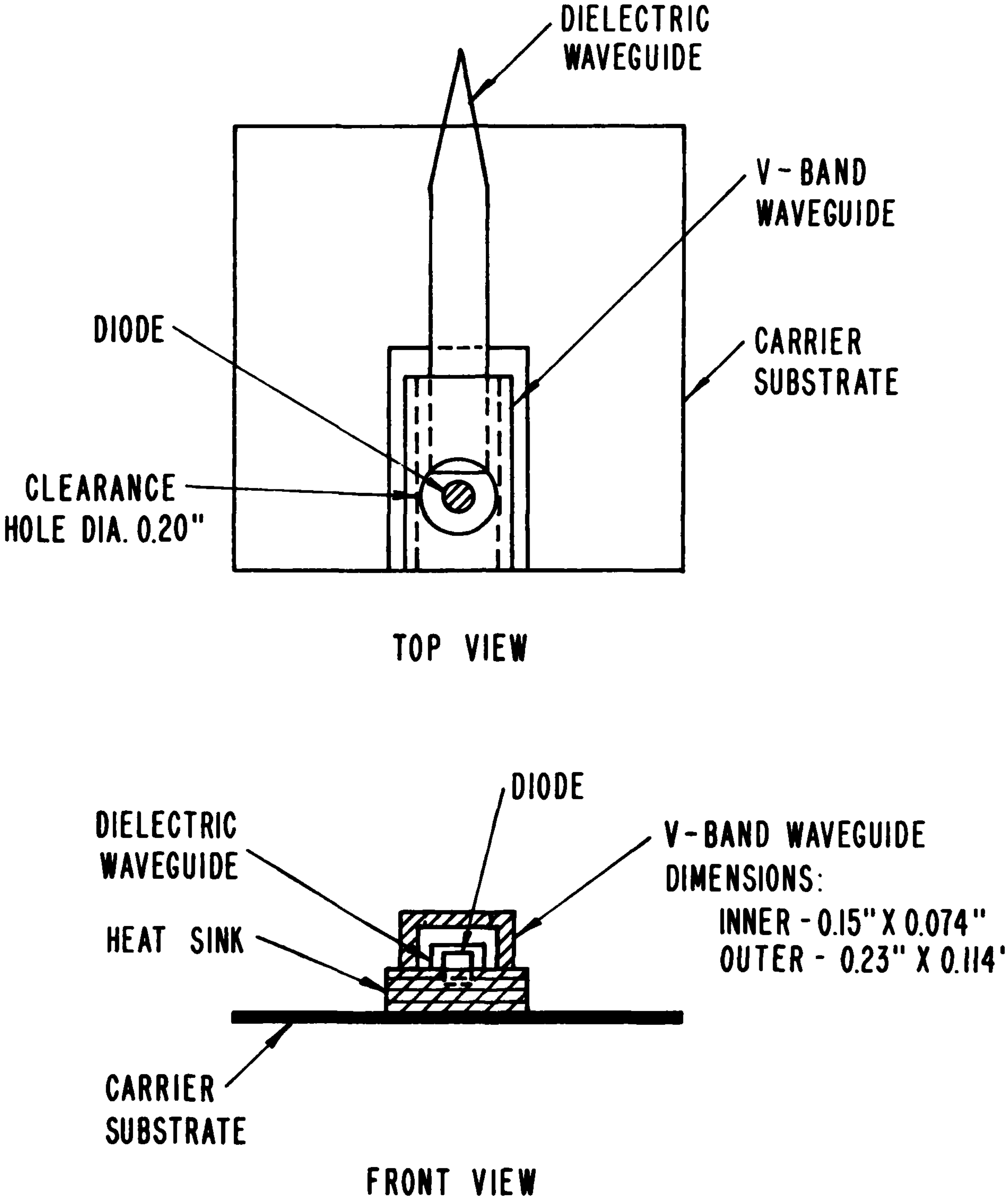


Figure 4. Diode Assembly Inclosed Within Rectangular Waveguide

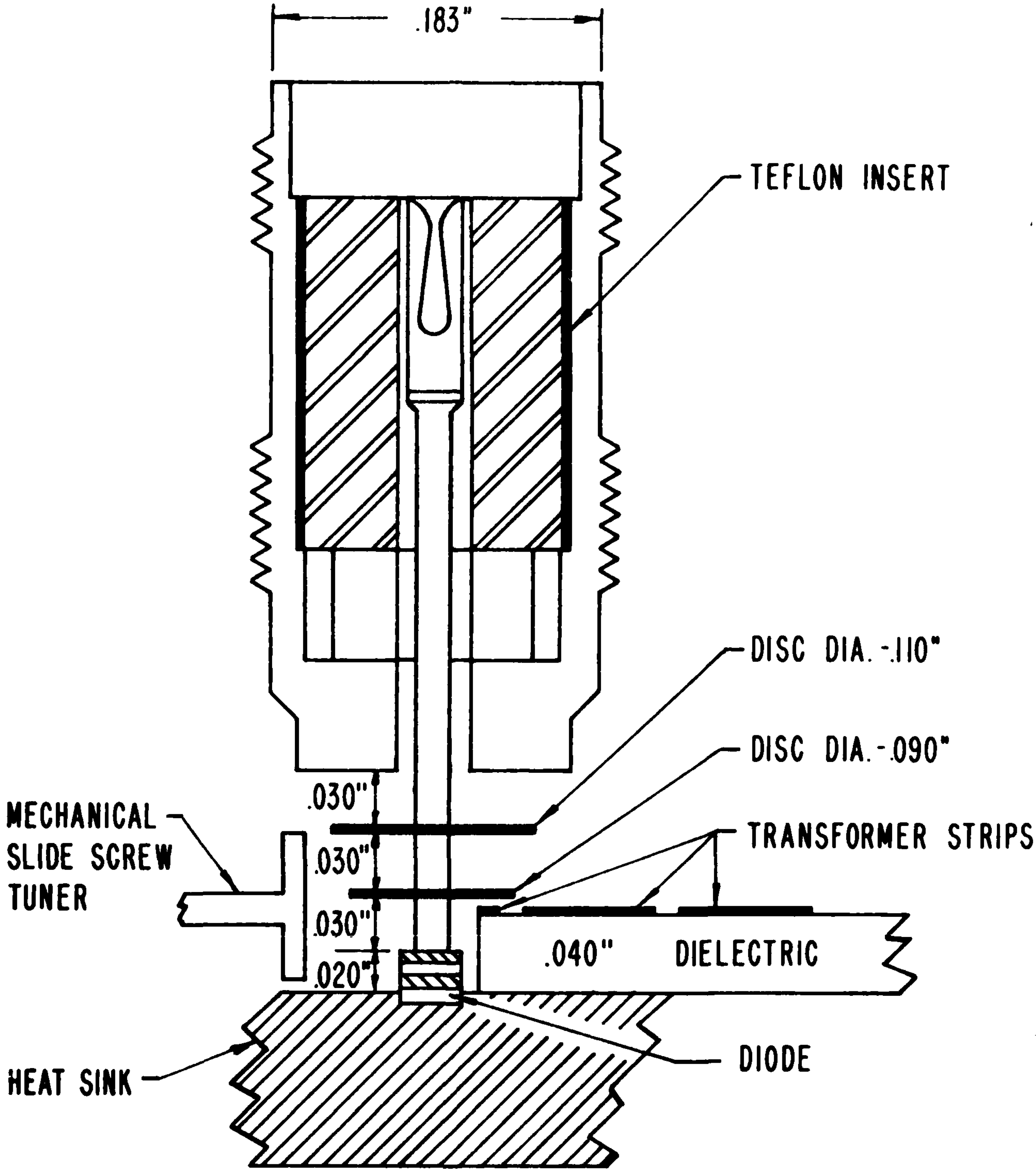
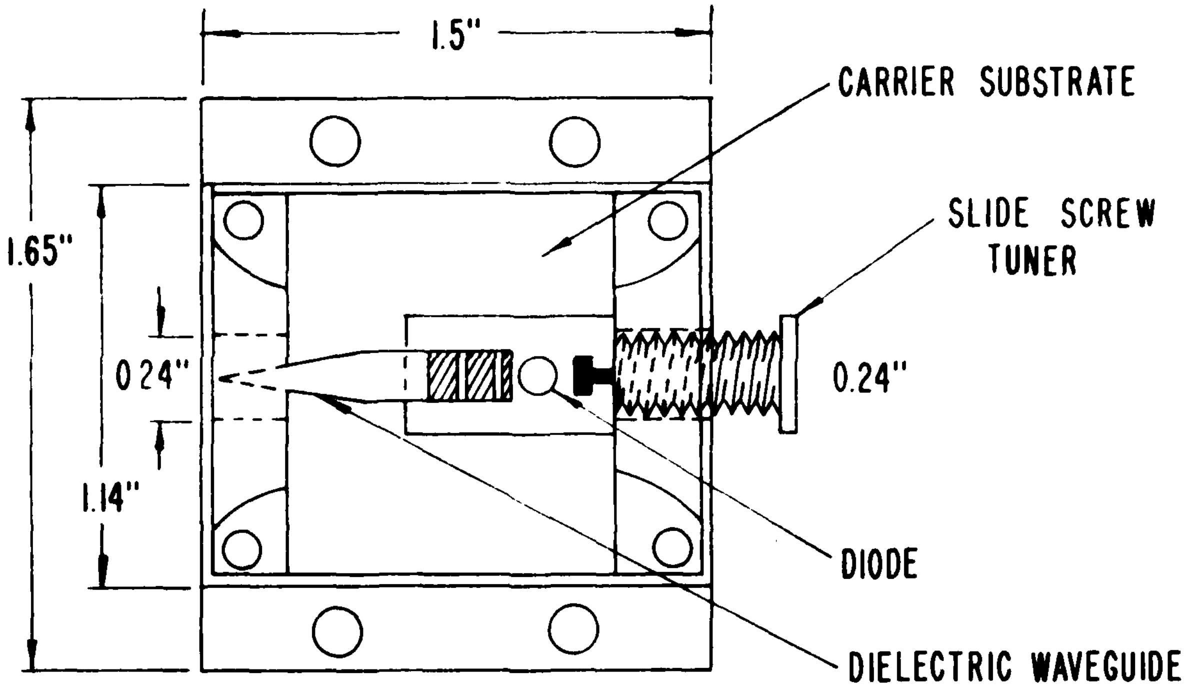
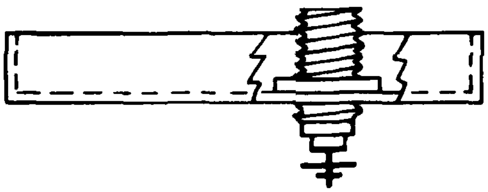


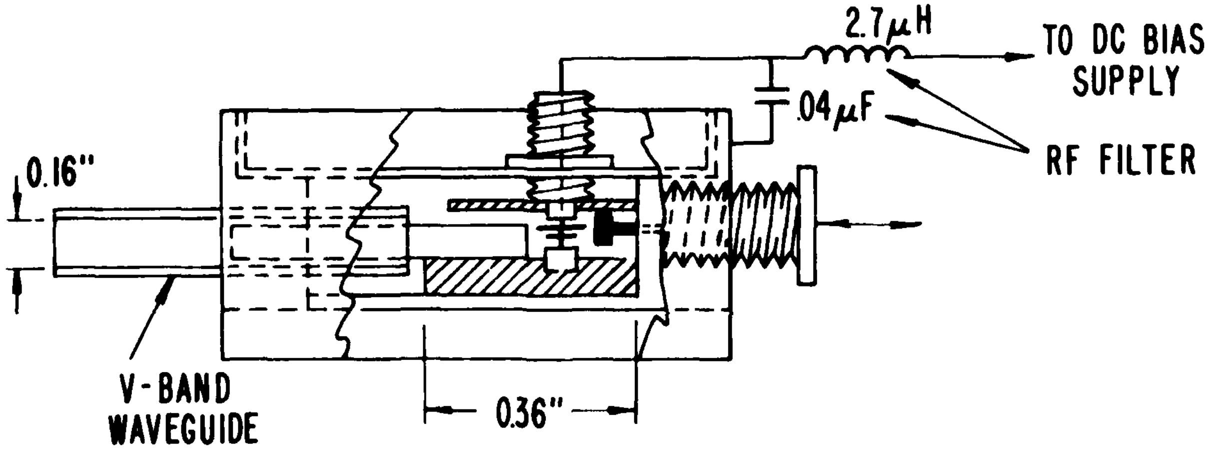
Figure 5. Modified RF Connector With Discs



TOP VIEW WITH V-BAND WAVEGUIDE REMOVED
AND DC INPUT CONNECTOR AND COVER REMOVED



DC INPUT CONNECTOR AND COVER (SIDE VIEW)



TOP VIEW WITH RF CONNECTOR AND COVER
INSTALLED AND V-BAND WAVEGUIDE CONNECTED

Figure 6. Diode Mounted In Metal Box

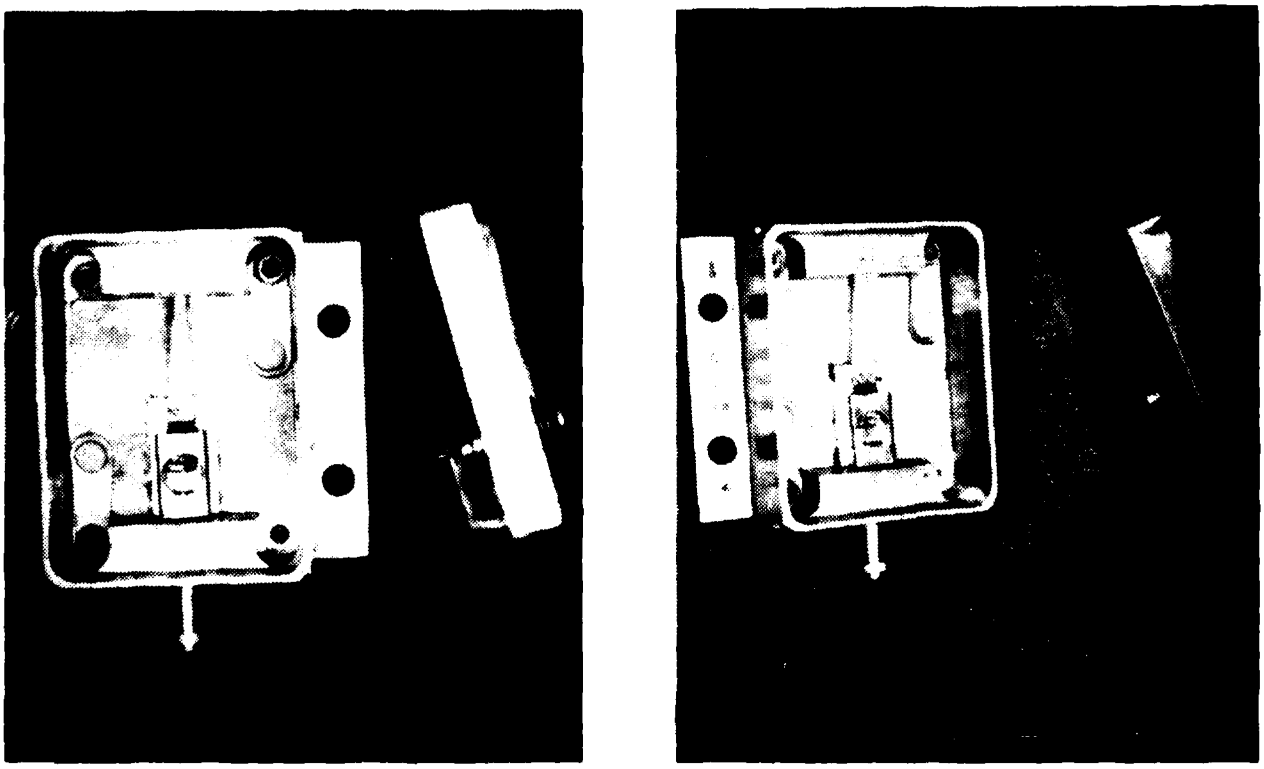


Figure 7. Gunn Oscillator Construction